The Naviglio Grande in Milan: a study to provide guidelines for conservation

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Abstract

The "Naviglio Grande", is part of a system of canals which ran through Milan, coming from two rivers, the Ticino and the Adda, which run west and east of Milan. The early embankments of the canal, which dates back to 1187 according to historical documents, were made with earth or gravel, and were later on substituted by masonry walls made with bricks and "ceppo", a natural conglomerate. These embankments are now affected by serious decay which has caused partial collapse in several areas; the Lombardia Region commissioned the Politecnico guidelines for the repair and conservation of the historical part of the bank. The aim of the research carried out by the authors was therefore to define a methodology of investigation to assess the damage and to suggest to the municipality of Milan (who are responsible for the Naviglio), a reliable technique for repair and preservation of the ancient bank walls. The historical reconstruction of the embankments characteristics and the on-site and laboratory investigation allowed us to suggest the appropriate techniques to halt the decay of the bank walls.
Keywords: canals embankments, stones, mortars, masonry, stratigraphic survey, non-destructive technique.

1 Introduction

The Naviglio Grande is part of a complex canal system that ran through Milan until the early 20th century marking its urban image in a most peculiar way. Documents date it back as early as 1187 although it was completed only in the 14th century. It was designed both to irrigate fields and to allow inland navigation. It was originally embanked with mounds of earth or gravel

("morognate") confined and sustained by timber piles ("passoni") that were fixed in the canal bed and linked through planks. As the city expanded along the Naviglio's banks and needs for speed and efficiency in water transport grew, new masonry embankments made of brickwork and of "ceppo d'Adda" (a local natural conglomerate) replaced the old ones, in order to reach higher strength and durability. Such works could only be carried out during limited periods of the year, when the canals were drained/emptied for cleaning and maintenance. They were already envisaged in the building contracts of the late 17th century, but they only started in mid-18th century and lasted at least until the early 19th century.
Maintenance and repair works, however, had to be regularly carried out in order to grant navigation on the canal, as it is clear from the present inhomogeneous composition of the Naviglio's embankments, where blocks of "ceppo d'Adda" alternate with bricks, white and rose granite pebbles bound with mortar, and other stone materials. The Naviglio is therefore a "work in progress". It would be impossible to retrace and restore any supposedly "original" condition. This was the authors' premise in outlining the guidelines for a conservation plan that Lombardia Region (Organisation Unit for Public Works) commissioned to the Politecnico of Milan.

A number of decaying phenomena are presently affecting the Naviglio's embankment, which have deteriorated and collapsed in several areas. A wide portion of it had to be rebuilt a few years ago following a major collapse. The new reinforced concrete walling raised a major question concerning the coating, that is, how to make it easily distinguishable from the older portions, while taking into account the pre-existing morphological and textural features.

The study had to tackle a number of different problems, since at the beginning there was no indication concerning the canal's original geometry, the materials and decaying conditions. Accurate historical and archive document research helped to gain a thorough knowledge of the building techniques which had been successively applied over the centuries, as well as the materials being used. All signs of previous practices and uses involving the canal were also mapped. Along with this study the authors drew geometrical maps, to make an inventory of all building materials, to locate and assess decaying phenomena and to run chemical and physical analysis particularly of the old binding mortars still in place. Georadar tests, drillings to inspect the foundations and the back of the embankment wall, as well as some sample cores, helped to study the geometry of the walls and their inner structure. Maps and analysis were subsequently compared and interpolated with the outcome of the historical and document research to provide guidelines for conservation. The purpose was to stop decaying phenomena that might jeopardise the structure and to select best intervention techniques according to the specific textural and decaying features.

2 Documentary research for the knowledge of the construction techniques and materials

The historical- archive investigation had the aim to understand the main construction events of hand-manufactured goods, but also to analyse the different techniques of repairing interventions due to decay phenomena already occurred in the past. A documentary evidence of the preservation works accomplished on embankments walls between the end of nineteenth century and the first decades of the twentieth century. A careful bibliographical research of books published about Milan canals completed this first phase of the work.

The research aim, as already mentioned, is an accurate knowledge of hand-manufactured goods study in order to single out building techniques, materials and maintenance works. This information is, as a matter of fact a basic drawing up the preservation project. The historical research put in evidence how the Naviglio Grande embankments were a result of a succession of interventions, from early ones made of earth until the double leaf wall in brick and in “ceppo” followed by the slow and gradual replacement with stones extracted along the river Adda or with bricks of different qualities, colours and sizes. An interesting information supplied by the documents concerns also the foundation techniques, from wooden piles on which the embankment wall was resting during the first period, until the continuous foundation in bricks recommended by nineteenth century maintenance contractors in order to improve the embankments stability. Very often this intervention was not accomplished at all or was not properly made. For a further deepening of the information a visual survey of the masonry construction technique was carried out on site. The stratigraphic survey of the masonry allowed also detecting the “marks” of practices carried out in Naviglio in past times. In fact still the tracks of wash basins used by ladies for washing can be seen, so as the bollards where boats were anchored, the granite shelves on which the wooden gangways for embarkation were based, the tracks of ropes used to draw boats (Fig. 1, 2, 3). [1-7]

Figure 1: The Naviglio seen by the bridge of Valenza Street toward the dock, 1890.

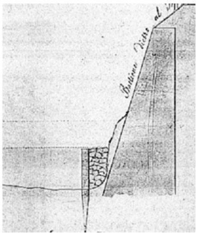


Figure 2: Section of "morognata" and "passoni" 1814.

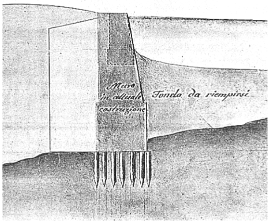


Figure 3: Section of masonry in brick s on poles, 1814.

3 Materials and decay mapping

At first a thorough geometrical survey campaign of the embankment prospects was accomplished starting from the straightening of general pictures. Subsequently local and general out of plumb and deformation of the walls were

measured. Graphical restitutions were reproduced on a 1:50 scale, even if the precision extent could allow a very good performance also on a 1:20 scale.
Then materials and decay pathologies were surveyed and mapped. The graphic mapping, is fundamental to delimit thoroughly the areas to be submitted to conservation intervention and also to identify the most suitable repairing techniques to be used (Fig. 4, 5). The masonry presently is composed by different materials, as said before. Wide made of “ceppo” blocks (25-30 centimetres thick), mainly with roughly worked surfaces, but also with smoothly worked blocks are present. By archives documents the “ashlar” in “ceppo” seem laid “in dry walling”, that is to say without mortar joints, even if such data could not be confirmed by the survey.

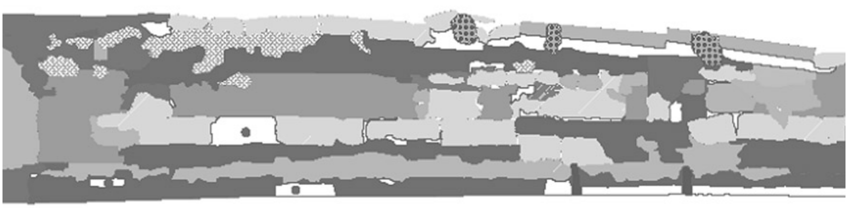


Figure 4: Survey of the different types of materials.

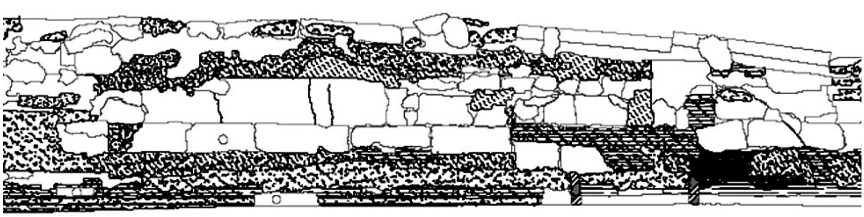


Figure 5: Survey of the stone decay.

Solid bricks of ancient manufacture were used in the past to fill voids left by missing stones. In the terminal part of the left embankment the masonry is finished with blocks of Baveno pink granite. The right embankment shows similar features, even if there is a later external part made of concrete.

During the on site survey of the material decay, the lack of some blocks of “ceppo” showed the presence of a masonry behind the stone carried out, at least for the visible parts, with solid bricks. Such observation, red in connection with historical documents, convinced the authors that in order to oppose the water thrust and the vertical loads, a double leaf wall was built: one leaf in “ceppo”, one in bricks. The whole thickness of the two masonry leaf reaches in some cases 1100mm with an average thickness of 800. It was not found any hint in the archive documents of existence of connections between the two leaves.

The foundations are also not homogeneous, as it could be deduced from the above-mentioned consignment Books of Navigli Grande and Bereguardo. If in the largest part of the investigated masonry portions, foundations walls do not exist (wooden piles, now decaying, can be surveyed only by marks) in other parts a brick masonry plate was found with different dimensions. This brick masonry show now deep gaps due to the water flowing action as well as to the canal cleaning operations along the times. The decay pathologies survey showed in addition the lack or deep erosion of mortar joints, as well as lack and gaps of the "ceppo" blocks; nevertheless the remaining blocks do not show decay phenomena due to the high porosity of the ceppo.

On the contrary the bricks are badly damaged. A biological attack by mosses often covers the masonry part over the water flowing line, while roots of upper plants (ailanto) cause damage and material expulsion. Finally the whole surface, in the submerged part, is coated by whitish consistent sediment, very thick attributable to a diffused alga on masonry (Fig. 4, 5).

4 On site and laboratory investigation on the embankment masonry

The experimental investigation carried out on site and in laboratory had the following aim: (i) to find the presence of a supporting brick or stone masonry behind the “ceppo” blocks, (ii) to detect its thickness, texture and consistency in order to provide the design for repair, (iii) to characterise the mortar and the bricks or stones, (iv) to find missing or badly decayed parts of the masonry supporting the “ceppo”.

4.1 Direct inspection of the embankment

A direct inspection was carried out in order to survey the masonry section. The first idea was to use non-destructive techniques for this investigation; nevertheless due to the difficulty of interpretation of the results, it was decided to carry out direct inspections. The easiest and less destructive way was to dig from the street as near as possible to the edge of the embankment. This inspection could be done also when the water was present in the canal and could give a clear indication on the wall section. Four small ditches were dug from the street floor, 1m deep, at chosen position of the embankment, three on the left (T1,T2,T4) and one on the right bank (T3).

The first ditch T1 showed at first the presence of a solid masonry brick-wall behind the stone blocks. By removing some more material behind this wall, another leaf emerged built with a different technique and with different bricks. The sequence of pictures in Fig. 6a,b,c shows the good technique and consistency of the first wall behind the “ceppo”. A second ditch T2 was dug on the left bank (Fig. 7a) and also in this case a solid brick wall was found behind the stones, while the second leaf behind is less homogeneous, and rather similar to a filling**.** The bricks belonging to the two masonries also appear to be different; nevertheless the presence of some concrete cover does not allow to make hypothesis on the materials, perhaps belonging to a late reconstruction.

The third excavation (T3) was made on the left bank; also in this case the masonry behind the “ceppo” appears to be very solid and made partially with bricks, partially with river stone pebbles (Fig. 7b). No other brickwork was found behind but only compacted soil (Fig. 7b). After the inspection of the left bank it was decided also to prepared a ditch T4 on the right bank. Also in this case a brick-wall was found, but with much less consistency than the others and signs of deep damages to the bricks and to the mortars (Fig. 7c).

Figure 6: a,b,c: Ditch T1: the sequence shows two masonry leaves, one behind the other.

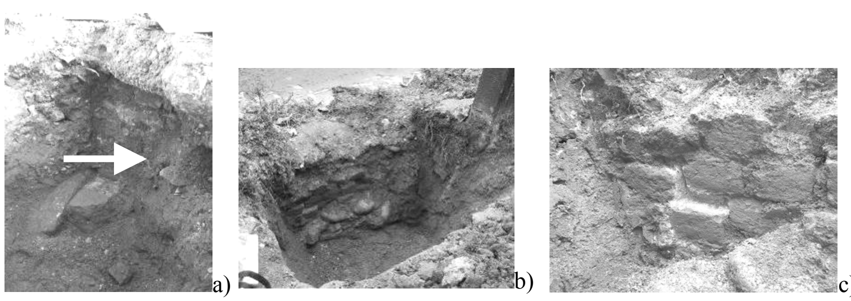


Figure 7: a,b,c: Ditch T2, T3 and T4; only for T2 the presence of two leaves was found.

During the excavation of T1 a certain quantity of mortar and bricks were sampled and taken to the laboratory for the characterisation.

4.2 Mortar characterisation

Five mortar samples were taken during the inspections from different positions enough in depth to be sure that the mortar was not the superficial decayed one and also could be the original one. Chemical analyses were carried out on the mortars: the binder was putty lime and the aggregate mainly siliceous (80-89%). The grain size distribution was rather well chosen and the mortar still in good conditions [8].

4.3 Coring and video-boroscopy of the masonry walls

When the canal was dried up for maintenance, it was possible to inspect the ceppo surface of the embankment and to drill some cores in order to measure the depth of the walls at different heights from the canal bed. Two heights were chosen: 500 and 1,500 mm). The walls were cored up to a depth of 1,200 to

1,300mm (Fig. 8a,b). As it can be seen from Fig. 8c the obtained cores are nearly completely damaged, due to the stresses and the washing out caused by the coring operation. Therefore, in order to detect the section of the wall a videocamera (Fig. 8a) was used and cored section was registered and could be drawn. In the hole at first the "ceppo" can be seen, then a clear mall void between the stone and the brick wall and at 1000mm a filling made with soil.

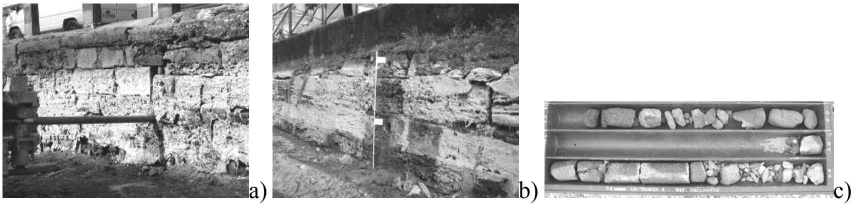


Figure 8: a,b: Coring at two different heights of the walls (450 and 1500mm) from the canal bed, c) one of the cores.

All the cores drilled showed a consistent wall up to 700- 800mm (Fig. 9a,b). Then a sort of rubble material with pieces of bricks or stones and mortar and finally soil. These observations confirm what was found by digging even more in depth.

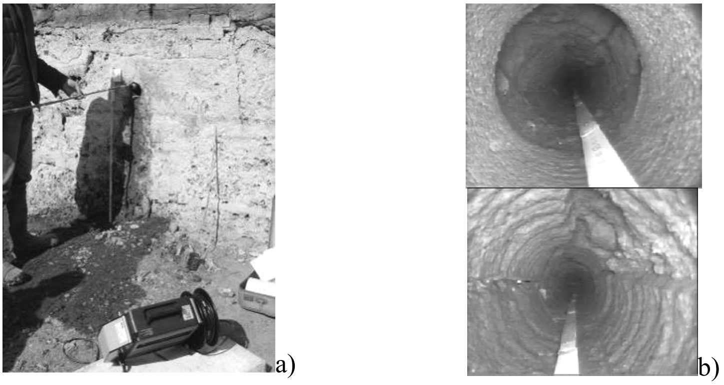


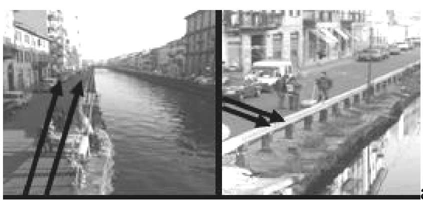
Figure 9: a,b: Videoendoscopy of the cored areas. Details of the holes.

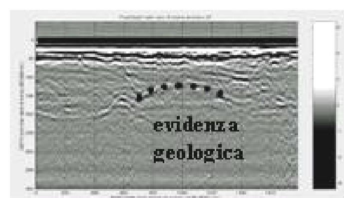
4.4 Georadar investigation

The Ground Penetrating Radar (GPR) is based on the detection of the velocity, amplitude and frequency of transmitted electromagnetic waves through a solid, by collecting the reflection of the transmitted signals [9-11]. The frequencies used for the investigation very from some tenth of MHz to some GHz. The higher is the frequency the higher is the resolution of the detected signals, but the lower is the reached depth particularly in a non-homogeneous material due to the wave attenuation.

The georadar tests can be efficiently used in the investigation on historic masonries to: study the wall morphology, find voids, flows and inclusions, presence of humidity etc. They are particularly useful when a large portion of walls needs to be detected. On the contrary the inspection and cores are very local, have to be limited because they are destructive. The aim of the georadar tests was to define the geometry of the wall section along a large part of the embankment, in order to control the results of the local inspections.

Two measurement campaigns were carried out. The first one along the street working on six profiles parallel to the canal bank for a length of 1,200 meters and 27 profiles normal to the bank at a distance of 1m for 105m (Fig. 10a,b). The test was carried out in order to control the depth of the embankment wall. Unfortunately these measurements were not so easy to interpret, due to the presence of numerous reflectors under the street level. The presence of several installations as electricity, water, telephone supplies and the lack of maps from the municipality to detect their position suggested to avoid using the results of this inspection. The only important information was the detection of a large geological evidence which could be found also by drilling cores as a bank of silty sand and mud 1300mm large at a depth of 8m (Fig.10c).

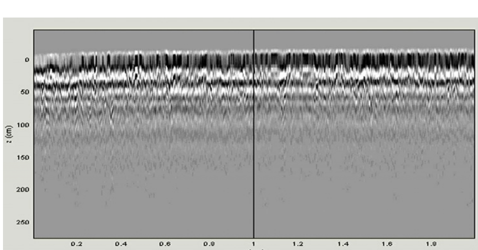

a,b)



c)

Figure 10: a,b: Profile directions, c) radargram of the soil section; a geological structure is present at 1300mm depth and 8m long.

The second campaign was carried out on the wall of the embankment from the side of the canal, once it was fried. The measurements were carried out on the left and on the right bank, along the “ceppo” surface, at 800 and 1,500mm from the canal bed. A 500MHz and a 250 MHz antenna were used along an extension of 1,220m. By comparing the radargrams it was found that the 500 MHz antenna allowed to reach the right depth. The elaboration of the data clearly indicates that the depth of the masonry is around 700mm on both the bank sides while the depth of the “ceppo” is 300mm (Fig. 11). It was also possible to find positions were the two walls were detached.



External layer

Thickness of the stone masonry wall (30 cm).

Thickness of internal masonry wall (70 cm).

Figure 11: Radargram showing the wall thickness and the two wall leaves.

The georadar results combined with the direct inspection and the coring allowed to have a complete information on the wall morphology, showing that these tests can work very well when used in combination, hence as complementary tests.

5 Preservation project and concluding remarks

On the bases of the above mentioned studies, the complementary use of historical investigation, stratigraphic and decay survey and experimental investigation allowed to identified the most appropriate techniques for repair and preservation. At first the cleaning of the wall surfaces will be carried out using water at low pressure; the elimination of mosses, after mechanical removal of roots of the largest plants, will be accomplished by poultices of products chiefly based on metositriazina. The re-pointing of the damaged joints will be carried out with new mortar based on natural hydraulic lime. No protective surface product will be used due to the fact that the remaining “ceppo” does not need it and for the brick surface it would be useless or even dangerous. In fact protective products based on organic materials have a short duration in a normal environment (1-3 years). In this case their duration will be no more than 6 months. The presence of gaps and missing parts of the masonry was an important subject of discussion among the designers. In fact the aim was to keep the marks impressed by time on the walls and to consider this last intervention only a further stratification of the complex palimpsest of canal. The compensation of the large “ceppo” stone missing parts was designed therefore to maintain the size of the ancient block but to change the type of stone using Montorfano white granite, already present in some stretches of masonry. Instead for small missing parts a repair by pieces of bricks and river pebbles was decides. In order to make easier the work for the operators, the masonry was subdivided in 28 areas “homogeneous” for materials and decay; for each area the interventions to carry out were indicated together with the relevant intervention cronoprogram (reported on drawings in scale1:20) (Fig. 12). During the intervention particular attention has furthermore to be paid to the marks of past uses of the canal (washtubs, disembarkation, marks of ropes, etc.) still remaining in place at least as tracks.

Reconstruction should only concerns those parts destroyed by recent collapses or unsafe. Such intervention must be subordinated to the real lack of historical material or to the impossibility of preserving it.

This second case as a rule should not exist. The project of new must be recognisable from the existent and avoid the restoration of the “status quo ante”. However any new intervention must become integrated with the existing, and be synthetically a further stratification of “Canal-palimpsest”. These principles lead to the decision of maintaining the external masonry leaves built in recent years, with reinforced concrete and to coat them with a compatible and recognisable material, that is with modern clinker bricks in dark red colour. For the base of the walls, exposed to continuous erosion by water flowing and object of mechanical damage during the canal cleaning, it was suggested the insertion of Baveno pink granite slabs. Concerning the part made of reinforced concrete and already coated with slabs of Ceppo from Iseo Lake, it was suggested to keep the coating interrupting the uniformity by a regular line of bricks (Fig. 13).

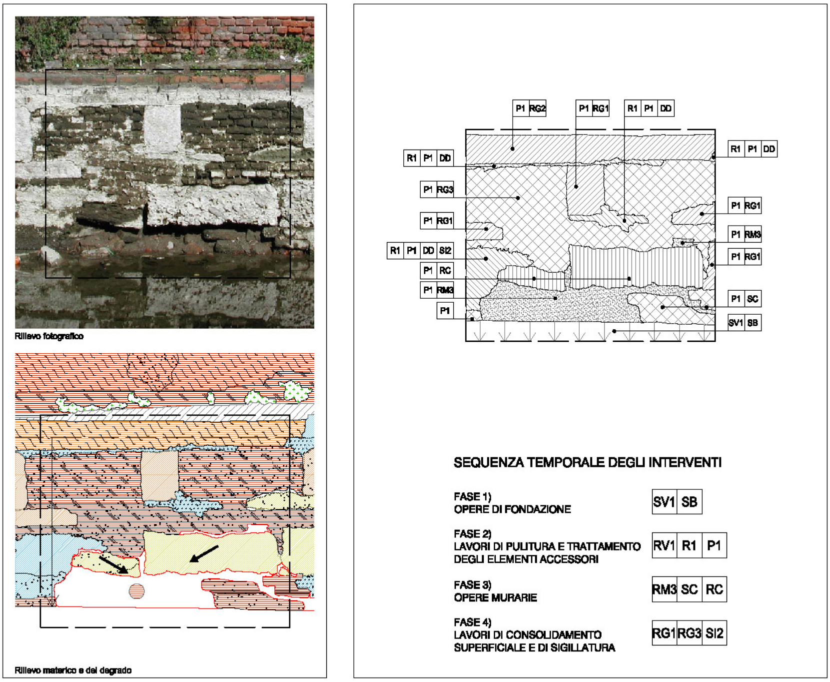


Figure 12: Example of design for preservation and repair.

Figure 13: Project for the improvement of the wall in concrete.

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